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by

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Comparison results are presented of the diurnal patterns for June 1976 simulated by a meteorological processor using as input the hourly NWS reports from Augusta and twice-daily radiosonde reports from Athens, Georgia (160 km northwest). The diurnal patterns were well approximated. Difficulties exist is properly characterizing the magnitude and timing of the wind maximum. The magnitude of the turbulent wind fluctuations was under-estimated some 15 to 20%, although the overall patterns were well simulated. It is seen that significant improvement can be achieved through the use of onsite measurements of temperature and wind fluctuations.

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*On assignment from the National Oceanic and Atmospheric Administration, U. S. Department of Commerce.

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1.0 INTRODUCTION

A meteorological processor for use in dispersion analyses is currently under development. The processor will be constructed using as a guide the methods outlined by two workgroups (Irwin, 1983; Holtslag et al., 1985). As part of the development effort, we have been investigating various techniques for assessing the performance of the meteorological processor. One such technique is to average the data by hour of day to produce time-height cross sections, depicting the average diurnal patterns within the data. This was done for the Wangara data (Clarke, 1974) using the 40-day series of hourly observations for comparison with several boundary layer models. The sharp changes in time and space are smeared by such a procedure. However, such averaged data are very useful for first assessment of the trends evident within a set of data. The purpose of this discussion is to summarize the results gained thus far in our use of such diurnal analyses of data.

Differences between a particular model's characterization of a process and that observed can arise for a number of reasons. Aside from

the obvious reasons that a model is a poor representation of nature or that the observations are in error, differences always occur because the time and space scales included within the modeling assumptions are not sufficient to prescribe the variations that occur in nature. It is beyond the capability of any model to resolve spatial or temporal fluctuations not included within the modeling algorithms. In certain circumstances these variations are of sufficient magnitude that they can obscure the broadscale features within the time series or spatial patterns of the observations.

The approach chosen in the following analysis is to smooth the results to develop monthly patterns of the diurnal course of the meteorological variables. Admittedly, the above procedure reveals only the broadest of features for comparison within the data. But then, we assert that unless the meteorological processor shows skill at this level of comparison, that there is little to be gained from comparisons that allow for time variations between days within a given month or between individual hours within a given day.

2.0 METEOROLOGICAL PROCESSOR FOR DISPERSION ANALYSES

The processor under development is entitled, Meteorological Processor for Dispersion Analysis (MPDA-1). Version 1 of the processor will offer a simplistic set of methods for processing three types of meteorological data for use in dispersion analyses: the National Weather Service (NWS) hourly weather observations, the NWS twice-daily upper air reports and user supplied onsite data. A selection of methods is made available for estimating the vertical profiles of wind velocity, temperature, and and the variances of the vertical and lateral wind speed fluctuations. Procedures are given for estimating the mixing height and the surface

layer scaling parameters, including the Monin-Obukhov (M-O) stability length. The goal is to initially accommodate Gaussian plume modeling techniques, and to expand the meteorological variable list, as needed in the future, to accomodate other dispersion estimation techniques.

It is beyond the scope of this discussion to list all the various methods and procedures included within MPDA-1. Furthermore, as the processor is still in the developmental stages it is subject to revision. For the cases to be discussed later, the input to the processor was restricted to only NWS data, namely the Augusta weather observations and the Athens upper air reports. The surface layer scaling parameters were estimated following the procedures discussed by Holtslag and Van Ulden (1982a,b). The procedures parameterize the surface energy fluxes in terms of cloud cover, time of day, near-surface wind speed, air temperature, and surface roughness (assumed to be 0.3 m). Monin-Obukhov (M-O) similarity relationships are used to estimate the M-O length, L, and the surface friction velocity, u_*, as continuous variables of the parameterized surface energy fluxes. The daytime convective mixing height is estimated using Garrett's (1981) model which employs the rate equations derived by Tennekes (1973) for a zero-order jump model coupled with a free-entrainment formula based on the work of Deardorff (1974). A procedure outlined by Benkley and Schulman (1979) was employed to correct the observed shelter temperature for large-scale advection effects, as estimated from the changes in the 700 mb temperatures between upper air reports. The surface temperature at the surface station and the upper air station may be different. The sounding is modified by adding the potential temperature difference to be representative of the surface station location. During those hours when mechanical mixing dominates, primarily the night-

time and the first few hours after sunrise, the depth of the mixed layer was estimated as $0.3\ u_*/f(1+1.9Z_i/L)^{-1}$, where f is the Coriolis parameter and Z_i is the mixed layer depth (Nieuwstadt, 1981). The temperature profile during the nighttime was estimated using Yamada's (1979) empirical expression for the potential temperature profile within the inversion layer, h, as

$$(\Theta-\Theta_i)/(\Theta_i-\Theta_s) = -\ (1-Z'/h)^c$$

where the subscript s and i refer to screen height (1.2 m) and inversion top, Θ is the potential temperature, $Z' = z - z_s$, z is height above ground, and c = 3. The inversion height (in meters) was estimated as at^b, where a = 70, b = 0.5, t is time in hours since the maximum surface temperature has been attained (Anfossi et al., 1976). During the daytime the potential temperature is assumed constant within the convectively mixed layer. During the nighttime for heights above h and during the day for heights above Z_i, the temperature profile is estimated from the twice-daily upper air reports, interpolated in time. The wind velocity profile and the turbulence profiles are determined using the procedures outlined by Holtslag et al. (1985). Similarity functions are used to estimate the vertical profiles of wind speed and turbulence within the mixed layer. The procedures outlined by Van Dop et al., (1981) are employed to match the wind profiles below Z_i, as estimated using similarity formulas, to the wind profile above Z_i, as determined from the twice-daily upper air reports.

The methods outlined are simplistic and there are obvious flaws. Our intent was to document the performance of the meteorological processor when exercised using a minimum amount of meteorological input. This provides a reference level of skill from which to measure the benefits of employing alternate processing methods and increased usage of onsite measurements of wind and temperature profiles.

3.0 METEOROLOGICAL DATA SET AND SITE DESCRIPTION

The data were collected during the period 1975 through 1979 by the Meteorology Group of the Savannah River Laboratory (SRL), Atomic Energy Division, E.I. du Pont de Nemours & Company. These data contain 15-minute averages and standard deviations of temperature, wind speed, horizontal wind direction and vertical wind direction. The data were collected on the WJBF-TV tower at seven elevations above ground: 10, 36, 91, 137, 182, 243 and 304 meters. The WJBF-TV -- SRL Meteorological Facility, is 11 km southwest of Augusta, Georgia and 23 km southwest of Aiken, South Carolina. Twice daily radiosonde reports are available from Athens, Georgia (160 km northwest). The 365 m tower, whose base stands 121 m above mean sea level, has been in use as a meteorological tower since October, 1965. The instrumentation and several features of the SRL program are summarized in Cooper and Rushe (1968). The instruments are mounted on heavy booms extending about 3 m outward (direction 225°) from the tower. Using the results of Gill (1967) it was determined that the tower would significantly affect the measurements of wind direction in the 50° sector from 355° to 45°.

The WJBF tower is one of three TV towers near the rural community of Beach Island, South Carolina. There is no one dominant form of land use in the immediate vicinity of the tower. Along any given azimuth from the tower, the rolling terrain varies with pine trees forests (heights approximately 10 to 20 m), pastures and fields, and clearings of waist high scrub and young saplings. The terrain is similar to much of the southeast piedmont region of the United States. Comparisons of the spectral scales and standard deviations of the fluctuating velocity components computed from the WJBF tower data with similarity theory models (Weber et al., 1982) found reasonable agreement.

4.0 DIURNAL ANALYSES

For each month, the data were grouped into 2 hour blocks, with 00-02 local standard time being the first block. A total of 8 (four 15 minute periods per hour) times the number of days in the month (about 240) were possible in each 2 hour block at each height. Missing and questionable data would, of course, reduce this number. The values within each 2 hour block were sorted, lowest to highest, allowing definition of the percentile values. For the diurnal patterns, the medians of the values were defined. Medians were not defined when less than 100 values were available as they were found to be erroneous in comparison to adjacent values in time and space. For plotting purposes, undefined medians were estimated by linear interpolation between adjacent values in time.

Figures 1 and 2 depict the observed variations for the months of February and June during 1976. For these particular plots, no interpolation was required to fill in undefined median values. Each of these plots was developed by an objective contour analysis employing the 7 by 12 array of median values, seven heights and twelve 2 hour blocks. The meteorological variables summarized are potential temperature (C), wind speed (m/s), the standard deviation of the horizontal wind direction (degrees), the standard deviation of the vertical wind direction (degrees) and wind direction change (degrees). The wind direction change was defined by subtracting the value of the wind at 10 m from the values reported at the other heights.

The 10 meter data were collected on a separate tower located approximately 80 m south of the main tower. A comparison of the 10-m data with the data collected on the main tower, to check for consistency, suggested that there was no noticeable bias in the wind speed or direction

data, but there were some differences noted in the temperature data. We speculate that these differences arise due to a difference in ground cover between the two sites. An estimate of the bias was developed based on an analysis aimed at detecting superadiabatic lapse rates between the 10 and 36 m levels during the nighttime and inversions between these two levels during the daytime. The average temperature correction was estimated by jointly minimizing the occurence of these events. The corrections were determined for each month, ranging from -2.83°C in December to +0.99°C in July, and were applied to the 10 m temperatures in all succeeding analyses.

5.0 SEASONAL ANALYSES

After inspecting a number of the diurnal patterns for each month for each meteorological variable, characteristic (key) features of these patterns were chosen for analysis over the 5-year period. As a working criteria in the selection of these features, we selected those qualities that if well approximated would strongly promote the proper description of the observed diurnal patterns for each month.

As an example, consider the potential temperature patterns in figure 1. The potential temperature is nearly constant within the well-mixed afternoon. As a first order approximation, knowing the maximum 10-m temperature and the time of occurrence defines the afternoon temperature profile. The surface based temperature inversion in the early morning hours is consistently strongest when the 10-m temperature is at a minimum. Knowing the inversion strength, the minimum 10-m temperature, and the time of occurence provides a definition of the early morning vertical temperature profile. To approximate the diurnal course of the temperature, a linear interpolation in time can be used between these two simplified

representations of the temperature profiles when the 10-m temperature is at a minimum and at a maximum. Hence, the monthly diurnal patterns of potential temperature can be well described in terms of three qualities: the magnitude and timing of the 10-m maximum and minimum temperatures, and the strength of the temperature inversion over lower 300 m at the time when the surface minimum temperature occurs. A similar line of reasoning can be applied for each of the meteorological variables.

Table 1 lists the key features selected for analysis for each of the meteorological variables. An inspection of the time series of values determined suggested strong seasonal dependence for some of the key features. A procedure was established for determining a best fit sine wave to the key feature values, as an aid in assessing the sesonal dependence. The period was assumed to be one year. The general equation has the form,

$$y(t) = a + b \sin (ct + d) + e(t) \qquad (1)$$

where y is the key feature value, t is the month number (January 1975 = 1; December 1979 = 60), c is the period (fixed at $\pi/6$), and e is a random variable of mean zero. The values a, b and d are found such that the sum of the deviations squared (sum of e^2 over all values) is a minimum. Given a and d, it can be shown that b can then be determined as,

$$b = [\Sigma (y-a) \sin (ct + d)]/[\Sigma \sin^2 (ct + d)].$$

The best fit value for the phase, d, was determined iteratively. a is the mean value and b is the amplitude. As there was only one time series available for estimating parameters, a jacknife procedure was used to determine confidence limits on the best fit estimates for a and b. As an alternative to the model provided by Eq (1), one could hypothesize that there exist no significant seasonal trends. In such cases, the y values might be modeled as,

$$y(t) = \bar{y} + e(t) \qquad (2)$$

where $\bar{y}$ is the average. An F-test can be used to test whether the variance is significantly reduced in using Eq (1) over that obtained using Eq (2).

Table 2 lists the curve fitting results for those key features for which the F-test suggest the seasonal dependence is significant. Table 3 lists the relevant statistics for the other key features. The results presented in Table 3 suggest that the timing, when events occur such as the 10-m maximum temperature, is fairly consistent. Figure 3 depicts the results obtained for the nocturnal wind speed maximum and the nighttime inversion strength. Whether the seasonal variation depicted for the inversion results is significant is questionable as noted in Table 2. Figure 4 depicts the results obtained for the 10-m values of maximum wind speed and maximum temperature.

The strong seasonal dependence in the 10-m temperatures was expected. The 304-m potential temperature at night are seen to be very similar to the average monthly temperatures. The amplitudes for the temperature features at 10-m in each case are the same, approximately 11°C. This suggest that on average the difference between the afternoon maximum and minimum 10-m temperature values is approximately 10°C, independent of season.

It is interesting to compare these results with the climatic trends discussed by Karl et al. (1984). For the period from 1941 to 1980, they found there was a trend for the monthly maximum temperatures to decrease with little corresponding change in the monthly minimum temperatures, resulting in a slow decrease in the diurnal temperature range over the period. The decrease was location dependent being more evident in the eastern states and the decrease was stronger for the winter months than the summer months. From the data presented, the decrease in the diurnal

range is typically less than 2°C over the 40-year period. In the analysis of the SRL tower data, this decrease would be indiscernable as it amounts to only a 0.25°C decrease in the temperature range over a 5-year period.

The results of comparing the above two models, Equations (1) and (2), suggest that seasonal variations can be detected and characterized. From a modeling point of view, the goal would be to compare well with the cycles and trends identified in the observations. Such comparisons allow assessment of the modeling skill in depicting diurnal, seasonal and annual trends.

6.0 MPDA-1 RESULTS

As an initial test of the meteorological processor, the processor was run for the month of June 1976 to specify hourly the meteorological conditions at the seven heights where SRL tower data were collected. The results were processed in an identical fashion as outlined in section 4. The diurnal summary analyses of the processor results are shown in Figure 5.

Comparison of Figures 1 and 2 with 5 reveals bias in the processor results. The potential temperature analyses are quite similar at the 10-m level, but aloft the values are 2°C low during the nighttime hours. For heights above h and Z_i at night, the temperatures are specified using the upper air reports. A correction was applied to the upper air temperature values so that they would be in accord with the hourly surface observations. This means that the bias shown in Figure 5, in comparison to the SRL tower data, must result from some other cause. Possibly the bias is produced by the linear interpolation in height for temperature values. During the late night hours, a linear interpolation will tend to underestimate data values. This effect contributes to the bias shown, but is

not likely to result in the 2°C bias. Most likely there are other factors, as yet undiscovered, contributing to the bias.

The wind speed analyses (Figures 1 and 5) are quite different. The major problem is that interpolation between sunset and sunrise upper air reports systematically underestimates the wind speed at 300 m during the nighttime hours. Improvement in characterizing the winds above the shallow nocturnal mixed layer would significantly improve the diurnal patterns generated.

In the investigating ways to improve the characterization of the nocturnal wind above the surface layer, we are currently assessing models of the geostrophic wind. There is a definite seasonal variation in the nocturnal wind speeds at 300-m. Stronger horizontal pressure gradients are anticipated with the winter storm systems, but a steady-state description of the time variation of the geostrophic wind may prove inadequate for our needs. There are other effects which possibly are important. Augusta is approximately 230 km from the South Carolina coastline. The close approach of the Gulf stream to this coastline would contribute to a strong horizontal temperature gradient between the land and the sea. This land-sea temperature difference represents a periodic thermal wind component to the geostrophic wind. This component varies systematically by season and time of day. Lettau (1967) and Anthes (1978) warn that accounting for periodic forcing functions may be expecially important in order to describe the time variation of vertically integrated boundary layer winds.

All things considered, the diurnal analyses for wind direction change are quite similar. The differences shown could easily occur considering the locations for the upper air reports and surface observations are

nearly 160 km apart. There is a bias towards underestimating the near surface values of wind fluctuations by about 15 to 20%. We do not believe this bias is a result of improperly characterizing the surface roughness length. Most likely, the bias results from conditions being other than ideal and the tendency for the simple turbulence models to underestimate the magnitude of the wind fluctuations within such circumstances.

To summarize, comparison of Figures 1 and 2 with 5 suggest that the overall diurnal patterns are well approximated, except for the wind speed results. Difficulties exist in characterizing the magnitude and timing of the nocturnal wind maximum. There is a bias to underestimate the magnitude of the temperatures at 300 m during the nighttime by about 2°C. There is also a tendency to underestimate the turbulent wind fluctuations by some 15 to 20%. These results were achieved using only the NWS observations routinely available. Use of onsite measurements of temperature and winds aloft during the nighttime hours would significantly improve the characterization of the meteorological conditions.

7.0 CONCLUSIONS

The preliminary results are encouraging for the use of monthly patterns of the diurnal variation of meteorological variables to assess the performance of a meteorological processor. Biases in the processor's characterization of the meteorological conditions are easily determined. The success we had in characterizing the seasonal variations in certain key features within diurnal patterns provides us with a direct means to assess the processor's performance in characterizing the broad scale variations in the meteorological conditions. By the nature of these comparisons of diurnal and seasonal patterns, not only is bias detected, but typically the cause of the failure is suggested as well.

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Table 1. Characteristic (key) features of diurnal patterns for each meteorological variable.

Potential Temperature
10-meter
average value
maximum value and hour of occurrence
minimum value and hour of occurrence
Nocturnal structure
inversion strength when 10-m minimum temperature occurs
Wind Speed
10-meter
average value
maximum value and hour of occurrence
minimum value and hour of occurrence
Nocturnal structure
maximum value, height and time of occurrence
gradient in the vertical between maximum and 10-m value
Wind Direction Fluctuations
10-meter
average value
maximum value and hour of occurrence
minimum value and hour of occurrence
Horizontal Wind Direction Shear
maximum value, height and time of occurrence

Table 2. Summary statistics for key features for which a seasonal dependence proved significant. N is the number of data values. a, b and d are defined in equation (1). The values within brackets are the 95% confidence bounds. The units are given to the left for each feature.

	N	a	[a]	b	[b]	d
Potential Temperature						
10-m level						
Average (C)	54	17.0	[16.4,17.6]	-10.9	[-11.9,-9.9]	$\pi/3$
Maximum (C)	55	22.4	[21.6,23.1]	-11.0	[-12.1,-9.8]	$\pi/3$
Minimum (C)	54	12.6	[12.1,13.1]	-10.8	[-11.6,-9.9]	$\pi/3$
Nocturnal structure						
304-m level (C)	49	18.8	[18.1,19.6]	-8.6	[-9.8,-7.4]	$\pi/3$
Inversion (C/100m)**	54	2.2	[2.0, 2.4]	0.8	[0.5, 1.0]	$\pi/2$
Wind Speed						
10-m level						
Average (m/s)**	45	2.4	[2.3, 2.5]	0.4	[0.2, 0.5]	$\pi/6$
Maximum (m/s)	49	3.2	[3.0, 3.3]	0.5	[0.3, 0.7]	$\pi/6$
Minimum (m/s)	48	1.8	[1.7, 1.9]	0.3	[0.2, 0.4]	$\pi/6$
Nocturnal structure						
Maximum (m/s)	31	10.4	[10.0,10.8]	2.2	[1.6, 2.8]	$\pi/3$
Wind speed gradient (s^{-1}x100)**	28	29.9	[28.1,31.7]	6.0	[3.1, 8.8]	$\pi/3$

** Not significant at the 0.05 level, but seasonal dependence is strongly suggested by other related key features.

Table 3. Summary statistics for key features for which a seasonal dependence did not prove significant. N is the number of data values, $\bar{y}$, is the annual average and s^2 is the variance. The values within the brackets are the 95% confidence bounds. The units are given to the left for each feature.

	N	$\bar{y}$	$[\bar{y}]$	s^2	$[s^2]$
Potential Temperature					
10-m level					
Time of maximum (hr)	55	15.0	[14.7,15.2]	1.0	[0.7, 1.5]
Time of minimum (hr)	54	5.5	[5.1, 5.9]	2.4	[1.7, 3.7]
Nocturnal structure					
Inversion (C/100m)	54	2.1	[1.9, 2.4]	0.8	[0.6, 1.2]
Wind Speed					
10-m level					
Average (m/s)	45	2.4	[2.3, 2.5]	0.2	[0.1, 0.3]
Time of maximum (hr)	49	14.1	[13.6,14.7]	3.4	[2.4, 5.3]
Time of minimum (hr)	48	0.7	[23.3, 2.1]	22.2	[15.4,34.9]
Nocturnal structure					
Time of maximum (hr)	31	1.2	[0.3, 2.0]	5.5	[3.5, 9.9]
Wind speed gradient (s^{-1}x100)	28	29.2	[26.8,31.6]	39.4	[24.6,73.0]
Wind Direction Shear					
Time of maximum (hr)	49	4.8	[4.2, 5.4]	4.6	[3.2, 7.2]
Maximum (degrees)	49	15.6	[13.6,17.6]	48.5	[33.8,75.8]

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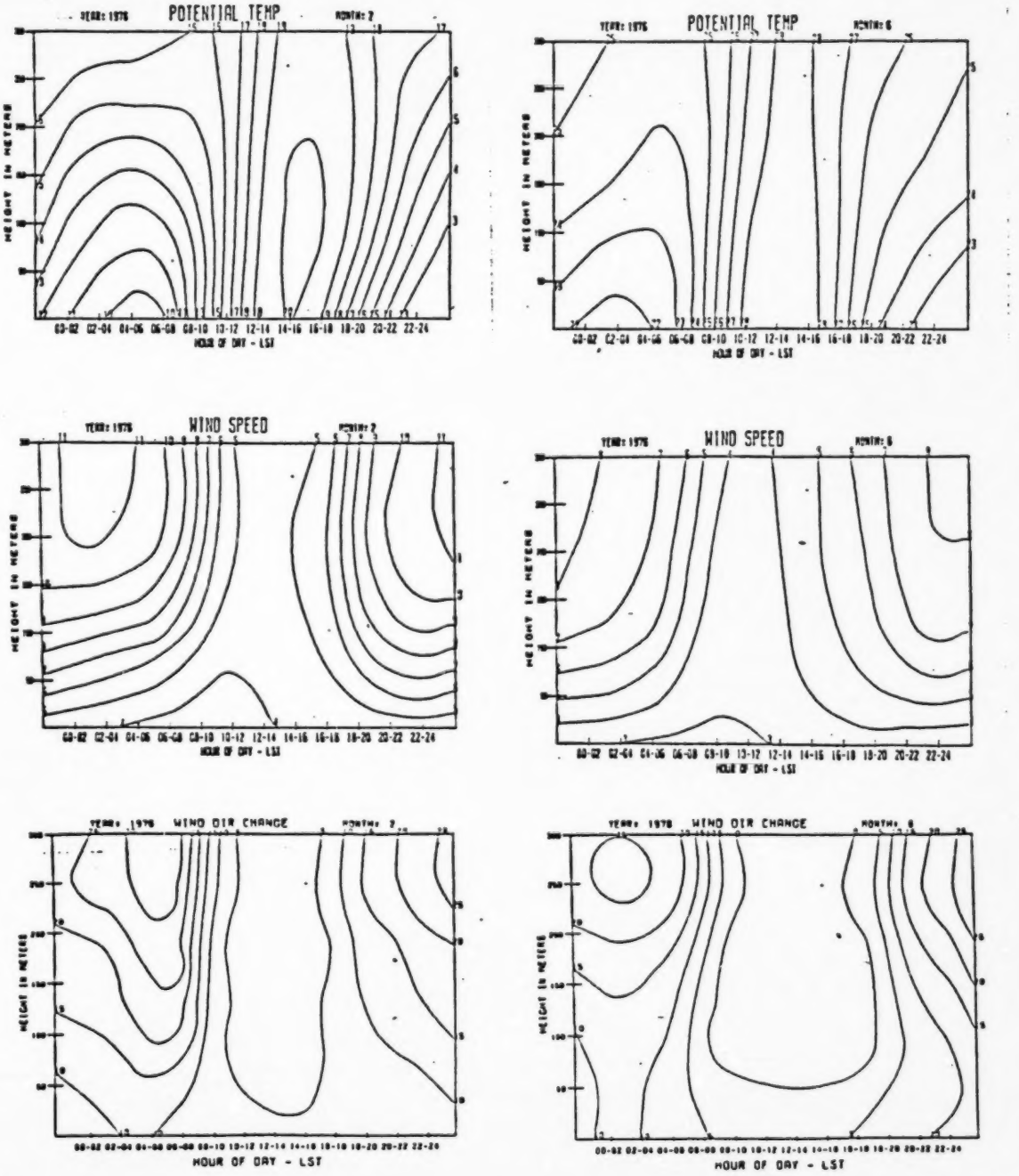

Figure 1. Diurnal variation of potential temperature (C), wind speed (m/s) and wind direction change (degrees) for the months of February and June during 1976.

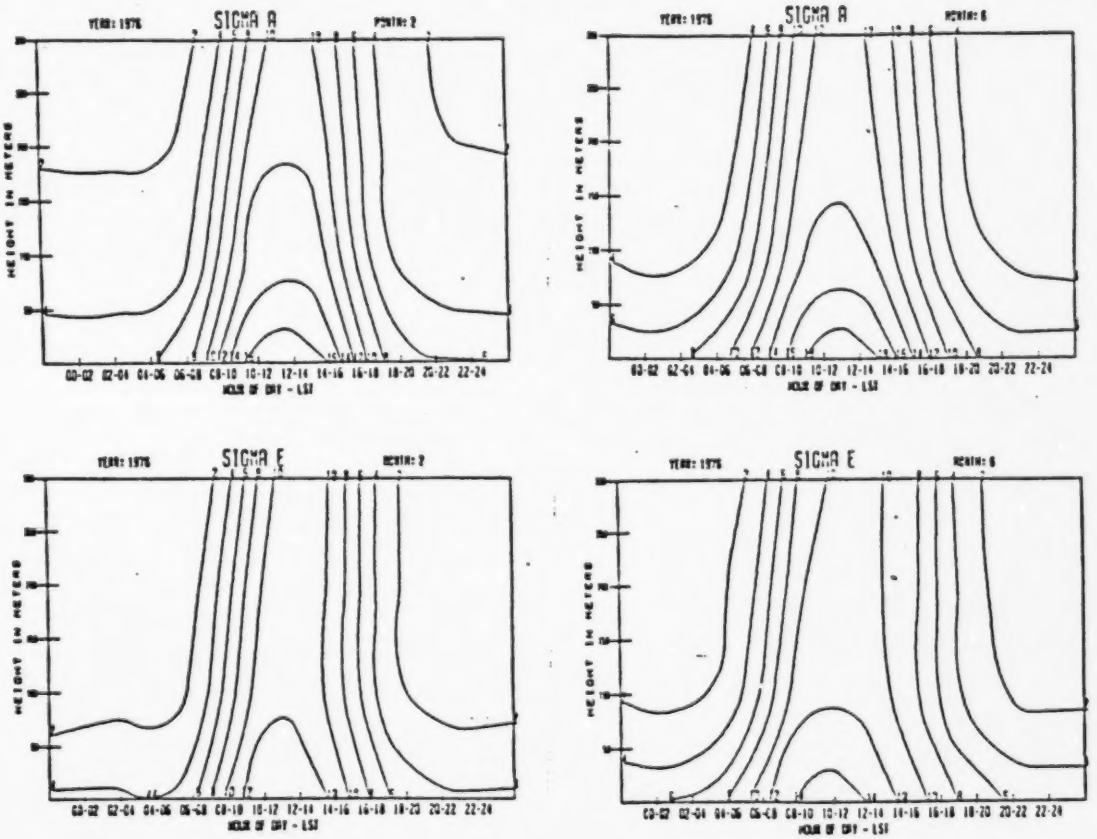

Figure 2. Diurnal variation of the standard deviation of horizontal wind direction (degrees) and of vertical wind direction (degrees) for the months of February and June during 1976.

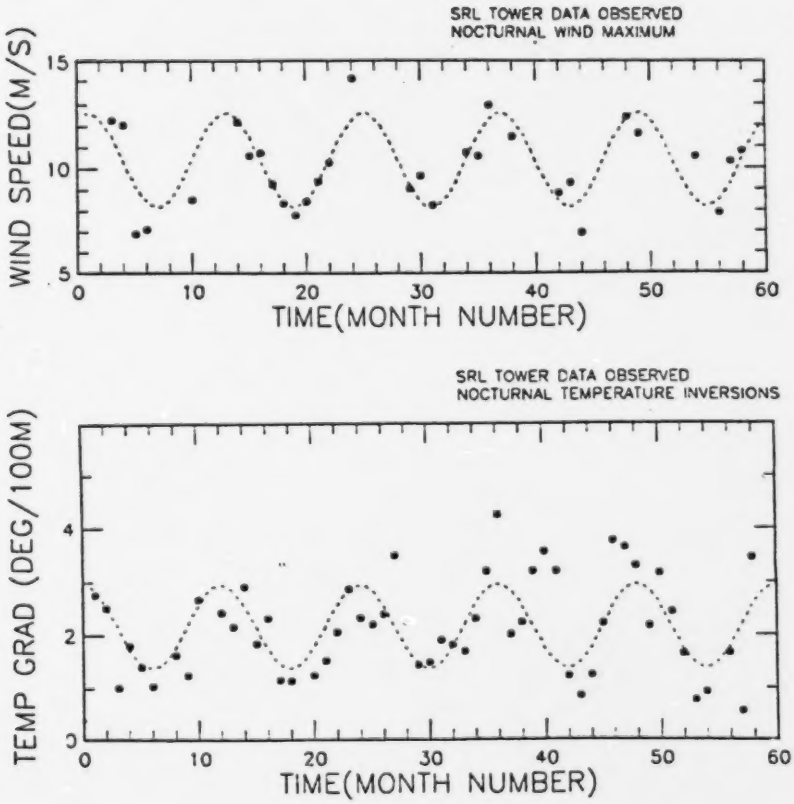

Figure 3. Median monthly values of the nocturnal wind speed maximum (m/s) and temperature inversion (C/100 m) determined for period 1975 through 1979. (Month 1 = January 1975; month 60 = December 1979)

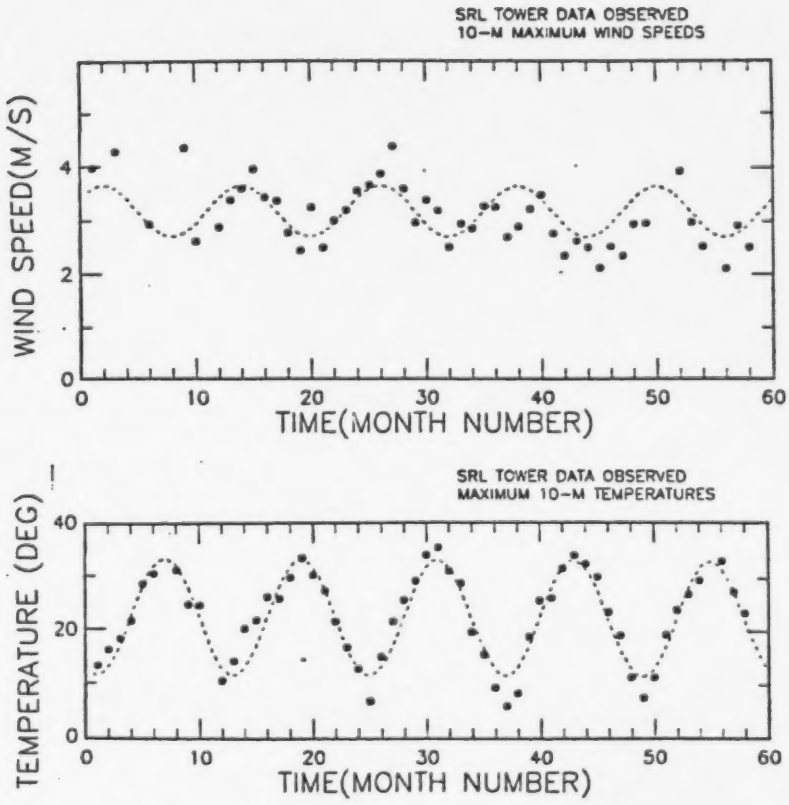

Figure 4. Median monthly values of 10-m maximum wind speeds (m/s) and temperature (C) determined for period 1975 through 1979. (Month 1 = January; month 60 = December 1979)

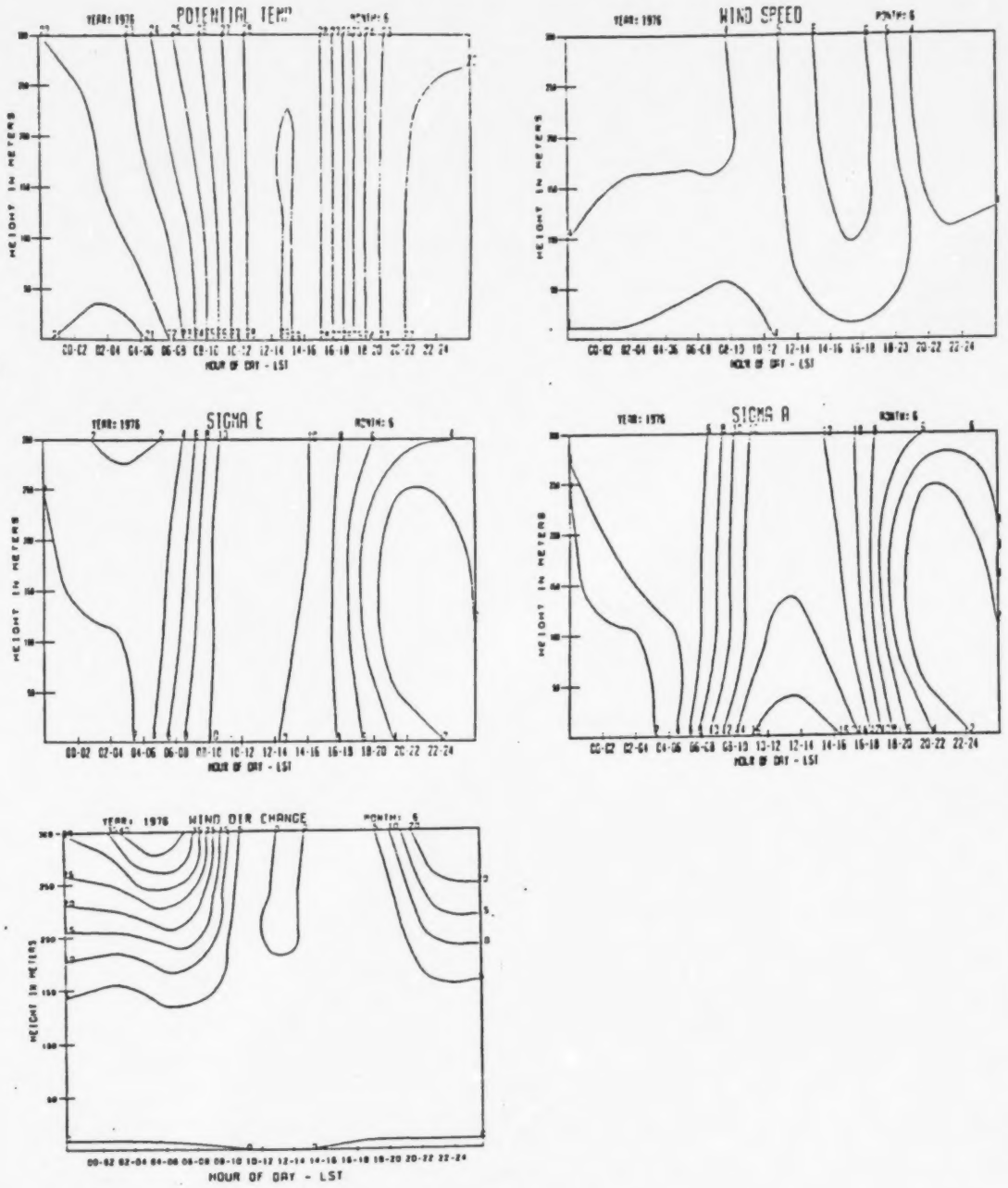

Figure 5. Diurnal variation of potential temperature (C), wind speed (m/s), wind direction change (degrees) and standard deviations of horizontal and vertical wind direction fluctuations (degrees) for June 1976 as depicted by meteorological processor using Augusta surface weather observations and Athens upper air reports.